Replacing fish-based feed with algae-based feed in aquaculture

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About this publication

This report is a condensed and targeted summary of key findings from the study: Advancing algae-based alternatives in EU aquafeeds: pathways to reducing fish-based ingredients as part of the Algae Industry Study, originally prepared by:

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Introduction

This document contributes to the implementation of the Action 7 of the EU Algae Initiative, which calls for specific guidance to promote replacing fish-based feed with algae-based feed.

Aquaculture production of carnivorous fish such as salmon, trout, and seabass currently depends heavily on wild-caught forage fish for fishmeal and fish oil. As aquaculture continues to expand and many fish stocks remain overfished, reducing this dependency has become an urgent priority. Identifying sustainable alternatives to fish-derived feed ingredients is therefore essential for both marine ecosystem protection and long-term food security.

Algal oil represents one of the most promising alternatives. Compared to fish oil, it offers higher and more stable levels of EPA and DHA, lower contamination risks, and more predictable pricing due to controlled production systems. Large-scale producers such as Veramaris and Corbion are already operating commercially, and major aquafeed companies including Cargill and BioMar have integrated algal oils into their formulations. Consumer acceptance is also evident: the retail chain Match reported a 12% increase in salmon sales after introducing salmon fed with algal oil enriched in EPA and DHA.

Despite this progress, barriers remain. Algal oil is still more expensive than fish oil, supply volumes are not yet sufficient to meet large-scale demand, and concerns persist regarding the sustainability and scalability of current microalgae production systems. Targeted financial instruments can help reduce production costs through economies of scale and technological improvements, while regulatory measures - such as stricter contaminant limits in fish products - can further stimulate market uptake.

Executive Summary

Purpose and scope

This document provides recommendations to support the gradual replacement of feed materials derived from wild-caught fish with algae-based alternatives in aquafeed. It focuses particularly on establishing practical inclusion levels for algae-based materials — especially algal oil — to reduce forage fish dependency and lower contamination risks in farmed fish.

The guidance builds on the WP1 report of the “Study to Support a Sustainable EU Algae Industry” ([1]) (CINEA and DG MARE). It also contains key information derived from the 2025 State of the Industry report on Algal Oil from the Centre for

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([1]) European Commission: European Climate, Infrastructure and Environment Executive Agency, Work package 1 – Advancing algae-based alternatives in eu aquafeeds – Pathways to reducing fish-based ingredients – Annex to the final report, Publications Office of the European Union, 2025, https://data.europa.eu/doi/10.2926/9094435

Feed Innovation ([2]). Some examples of best practices already adopted by the industry can be found in Annex A.

This document contributes to Action 7 of the EU Algae Initiative, which calls for specific guidance to promote replacing fish-based feed with algae-based feed.

Summary of conclusions

- **Incorporation targets:** Algae can technically replace fishmeal and fish oil, with partial substitution being the most realistic pathway in the short to medium term. Inclusion rates of 10-15% in salmon and trout feeds and 20–25% in seabass feeds are currently feasible. A 25% substitution of EPA+DHA from fish oil with algae oil may be achievable within five years, provided production capacity expands accordingly.

- **Target species:** *Schizochytrium* sp. (DHA source), *Nannochloropsis oceanica* (EPA and protein source), and *Chlorella* sp. (protein source) are particularly suitable microalgae candidates for aquafeed applications.

- **Performance, food safety and environmental impact:** Algae-based feeds achieve comparable feed conversion ratios (FCR) and growth rates (SGR) to conventional feeds, while improving fish quality and significantly reducing contamination risks. Even partial substitution lowers the Forage Fish Dependency Ratio (FFDR), contributing to marine ecosystem recovery.

- **R&D needs:** Scaling production requires major investments in fermentation infrastructure and access to sustainable, cost-efficient carbon sources. Further research is needed to:
  - Improve strain selection and productivity,
  - Enhance processing efficiency to improve nutrient bioavailability of algae as a feed material.

- **Legal and policy framework:** EU legislation already permits algae use in aquafeed, but a stronger enabling environment is required. Potential measures include:
  - Setting FFDR reduction targets,
  - Strengthening contaminant regulations under the ALARA principle,
  - Phasing out subsidies for unsustainable marine feed inputs,
  - Introducing tax incentives and financial instruments supporting sustainable alternatives.

([2]) CFI (2025). Algal Oil 2025 State of the Industry Report .2025 State of The Industry Report - Algal Oil | Centre for Feed Innovation

- **Industrial standards:** Clear sustainability criteria, nutritional standards, and health claims for algae-based ingredients can enhance market confidence. Certification schemes and sustainability standards can further accelerate adoption.

Strategically, integrating algae-based materials into aquafeed aligns closely with the objectives of the **European Ocean Pact**, the **Farm to Fork Strategy**, and the new **EU Bioeconomy Strategy**.

By reducing reliance on wild forage fish, algae-based feeds contribute directly to sustainable ocean governance, marine ecosystem restoration, and resilient seafood systems - core priorities of the European Ocean Pact. Lowering the Forage Fish Dependency Ratio (FFDR) supports healthier fish stocks, strengthens food security, and enhances the long-term sustainability of EU aquaculture.

Under the Farm to Fork Strategy, algae-based feed diversification promotes more sustainable and resource-efficient food production by reducing pressure on wild fisheries and lowering contamination risks. At the same time, the renewed EU Bioeconomy Strategy emphasizes circular, bio-based value chains and strategic autonomy in key raw materials. Expanding algae cultivation for aquafeed contributes to these goals by developing domestic bio-based production capacity, stimulating innovation, and creating green jobs in coastal regions.

Collectively, promoting algae-based aquafeed advances environmental sustainability, ocean resilience, and economic competitiveness - core pillars of the EU's long-term vision for a sustainable and productive ocean economy.

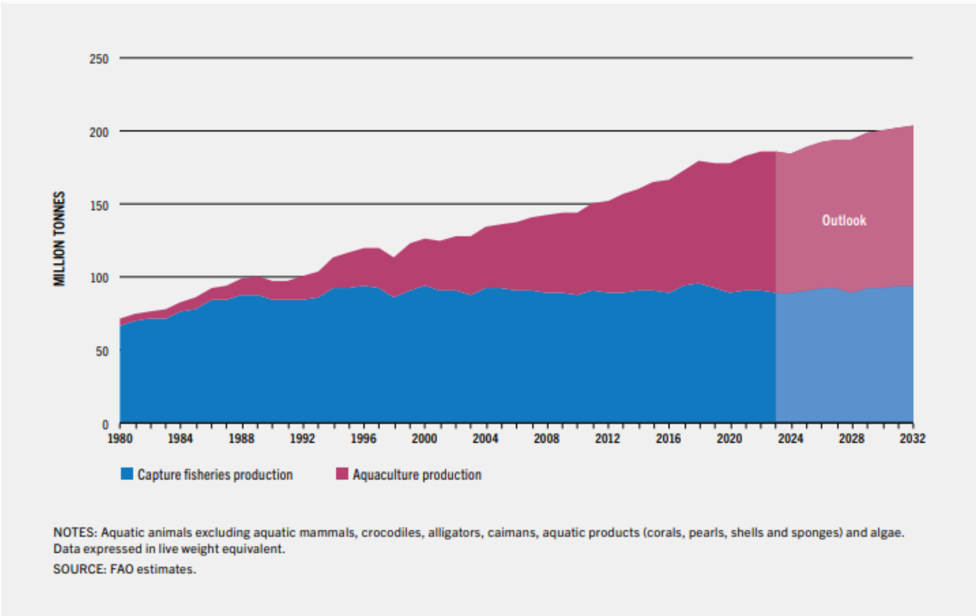
Accelerating the shift from fish-based to algae-based aquafeed represents a strategic opportunity for the European Union to lead the global transition towards restorative aquaculture, restore marine ecosystems, strengthen bio-based innovation, and build a resilient, future-proof seafood system.

1. Introduction

1.1. Background and policy context

Aquatic foods account for about 15% of the global animal protein supply and even exceed 50% in several countries across Asia and Africa. They are the most efficient animal-based protein source, with a high conversion from protein ingested to protein produced. For the EU aquaculture production, a growth of 8.9% is projected from 2022 to 2032, while global aquaculture production is estimated to increase by 17% during the same period (3), as can be seen in Figure 1.

Figure 1: World fisheries and aquaculture production of aquatic animals, 1980-2032



Source: FAO (2024). The State of World Fisheries and Aquaculture 2024 –
Blue Transformation in action. Rome, https://doi.org/10.4060/cd0683en

However, to enable fish to be raised in aquaculture, substantial amounts of feed are required. Traditionally, carnivorous species, such as salmon, rainbow trout, seabass, and seabream, have been fed primarily on wild forage fish, which are specifically caught for this purpose. Approximately 22% of the globally captured fish, representing 17 million tonnes (4) of wild fish, were processed into fish oil and fishmeal for non-food purposes in 2022, primarily as feed for aquaculture (3).

Globally, roughly **17 million tonnes of forage fish** are reduced annually into fishmeal and fish oil to help support the production of about **66 million tonnes of farmed finfish**, illustrating the continued structural dependence of aquaculture on wild marine resources despite significant efficiency gains in feed formulations.

(3) FAO (2024). The State of World Fisheries and Aquaculture 2024 – Blue Transformation in action. Rome, https://doi.org/10.4060/cd0683en

(4) Global Food Security | IFFO - The Marine Ingredients Organisation

Several companies are already producing and utilising algae-based materials to replace traditional fish-based components ([5]). Certain algae are especially rich in essential nutrients, providing protein and specific valuable omega-3 fatty acids, including eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), which are usually derived from fish oil. Algae are also rich in proteins with a balanced composition of amino acids, depending on the species. These distinctive characteristics make algae a particularly promising alternative for aquafeed.

In 2021, a Communication from the Commission entitled "Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030" ([6]) highlighted the need for ensuring sustainable feed systems and specifically mentioned algae to reduce the feed producer's reliance on fish meal and fish oil sourced from wild stocks. In 2022, the EU Algae Initiative announced, in a Communication from the Commission entitled "Towards a Strong and Sustainable EU Algae Sector" ([7]), 23 specific policy actions to accelerate the development of the European algae sector. Amongst them, action 7 aimed "to develop a guidance document to promote replacing fish-based feed with algae-based feed", which is the purpose of this report.

1.2. Current Landscape of Aquaculture Feed

1.2.1. Overview of fish-based feed in EU aquaculture

Aquaculture is the fastest-growing segment of the food industry and is projected to increase its global production by 17% by 2032 compared to 2022 ([8]). In 2022, 17 million tonnes of harvested aquatic animals (from both capture and aquaculture) were processed into fishmeal and fish oil ([9]). Of this, over 87% of fishmeal (2022) and 74% of fish oil (2021) were used in aquaculture ([10]).

The aquaculture growth and demand for fishmeal and fish oil led to a price increase as production decreased. There has been a strong imbalance in the

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([5]) More information on these companies can be found in chapter 6 of the original report and on page 44 of the 2025 CFI report.

([6]) COM (2021) 236 final of Brussels, 21.5.2021 Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 20221 to 2030. EUR-Lex - 52021DC0236 - EN - EUR-Lex

([7]) COM (2022) 592 final of Brussels, 15.11.2022. Towards a Strong and Sustainable EU Algae Sector. 4d5a28c9-8720-45e7-84f0-b1d076d60a60_en

([8]) FAO (2024). The State of World Fisheries and Aquaculture 2024 – Blue Transformation in action. Rome, https://doi.org/10.4060/cd0683en

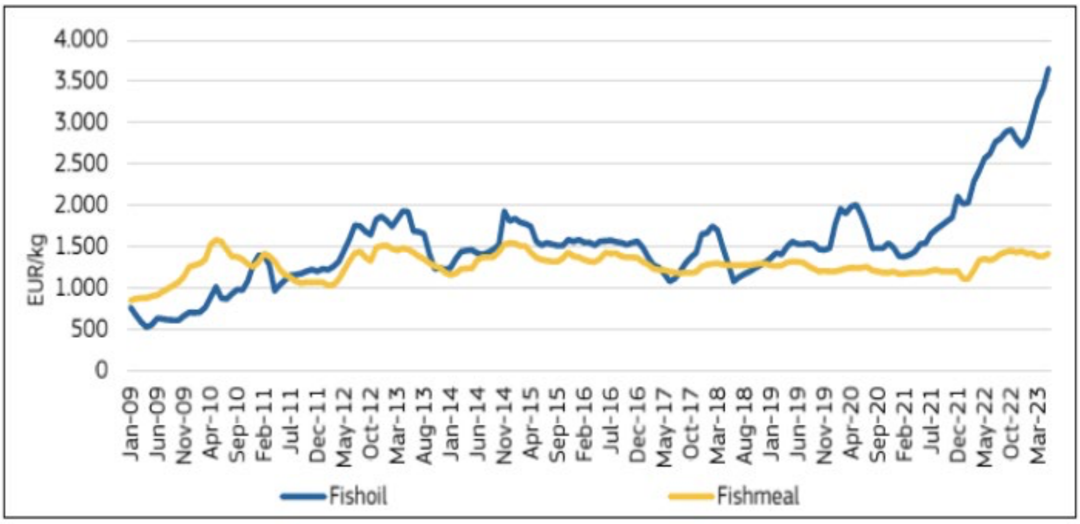
([9]) Around 21 kg of fishmeal and 2-6 kg of fish oil are produced from 100 kg of fish.

([10]) Same as (4).

supply and demand dynamics in the past few years, especially for fish oil. From 2011 until 2023, the prices of fish oil increased by around 181% while fishmeal prices increased by about 67%. This development also led to lower inclusion rates in aquaculture feeds ([11]).

The substantial increase in fish oil prices between 2021 and 2023 was driven by several factors. Peru, which is the world's largest fish oil producer from anchovies, implemented fishing restrictions to preserve anchovy, particularly due to a high presence of juveniles because of the impacts of El Niño. These restrictions led to lower catches, reducing the global supply, which in turn increased the prices of fish materials. The effect on fish oil prices was particularly noticeable (Figure 2), as there is currently no widely used alternative providing EPA and DHA, which are needed for many fish species to stay healthy, and it is also used for food supplements. Furthermore, the ongoing disruptions in global supply chains due to the COVID-19 pandemic and inflationary pressures in 2022 further exacerbated the price increases ([12]).

Figure 2: Fishmeal and fish oil prices in Europe



Source: Oilworld. Values are deflated by using the GDP deflator (base=2015).

Source: EUMOFA (2023). Fishmeal and Fish Oil. Available here.

Fish are harvested and processed into fishmeal and fish oil largely to supply EPA and DHA for aquaculture feed, yet these essential fatty acids originate from microalgae at the base of the food chain, making microalgae a more direct, logical, and higher-quality source for fish nutrition.

([11]) EUMOFA (2023). Fishmeal and Fish Oil. Available here.

([12]) Barreiro, L. (2022). "Aquafeed Outlook 2023: Prices, Novel Ingredients and Feed Efficiency". Available here.

To promote sustainability and reduce dependence on wild-caught fish, the aquaculture sector has been actively exploring alternative materials, such as high-quality plant components like soya, as well as materials derived from insects, poultry farming, algae, and seafood side streams. The use of fish trimmings from wild-caught fish as a source of fish meal and fish oil has also increased over time. From these, algae have emerged as especially promising alternatives due to their nutritional value, especially in terms of EPA and DHA content.

1.2.2. Environmental impacts of fishmeal and fish oil

The environmental impact of wild fish for feed has been assessed using the Life Cycle Assessment (LCA) methodology. For forage fish, the fuel consumption per tonne of catch is relatively low, primarily due to the efficient fishing methods that are employed ([13]). Some other aspects that are commonly considered in LCAs, such as the land use, are also low for forage fish as they are found in marine environments. Therefore, when conducting an LCA, the use of wild-caught fish in feed can often be considered advantageous, especially when compared to other materials in feeds.

However, LCAs usually do not account for certain critical ecological aspects like biodiversity or ecosystem preservation. Unsustainable exploitation of forage fish can have negative impacts on the key components of marine ecosystems. Therefore, new metrics were developed specifically for the aquaculture industry, such as the FFDR (Forage Fish Dependency Ratio) ([14]). The FFDR specifically accounts for fish-based materials from wild-caught fish used to produce one kilogram of farmed fish, excluding other sources such as fish-based by-products. It can be a valuable indicator for indirectly assessing potential impacts on biodiversity, overfishing, and ecosystem health in the context of aquaculture.

Nevertheless, the Marine Ingredients Organisation (IFFO) argues that marine materials can also be sourced from well-managed fisheries and therefore represent a sustainable resource for animal feeds. In this regard, they further assert that the assumptions regarding the environmental impact of forage fish exploitation are often overstated or not universally valid ([15]).

Assumptions aside, it has been estimated that, as of 2024, more than 37% of global fish stocks are already overfished ([16]). In 2021, such unsustainable stocks

([13]) IFFO (2024). The Evolution of Sustainability metrics for marine ingredients. Available here.

([14]) IFFO (n.d.). FFDR Data

([15]) Same as (10).

([16]) Marine Stewardship Council (n.d.). Overfishing. Available here.

accounted for 23% of the total wild fish catch ([17]). Among the remaining fish stocks, most are already at their maximum sustainable limits. Additionally, some experts caution that certain fisheries may be ecologically overfished, even if they are not officially classified as such ([18]). Therefore, the reliance on fish meal and fish oil, especially when considering a likely expansion of the aquaculture sector, will have important environmental consequences.

With the aquaculture sector expected to continue growing and wild fish stocks remaining finite, strategies should be implemented to increase the use of sustainably sourced alternative feed materials. This approach does not necessarily require total replacement, but rather targeted supplementation in aquafeeds to reduce the reliance on unsustainably sourced fishmeal and fish oil.

1.2.3. Contaminants in fish feed and fish oil

Contaminants present in aquafeed are relevant for food safety, as certain substances can accumulate in farmed fish intended for human consumption. Fish-based feed materials derived from wild forage fish may contain contaminants naturally present in marine environments and concentrated through the food chain, including dioxins, polychlorinated biphenyls (PCBs), and, in some cases, heavy metals. Heavy metals are more commonly associated with the solid fraction (fishmeal), whereas refined fish oil typically undergoes purification processes that significantly reduce heavy metal concentrations. However, dioxins and PCBs - both persistent organic pollutants - tend to accumulate in fatty tissues and are therefore more closely associated with fish oil ([19]). These compounds originate from historical industrial uses and combustion processes, persist in the environment, and can bioaccumulate over time. Long-term exposure has been linked to adverse effects on the nervous, immune, endocrine, and reproductive systems, as well as increased cancer risk ([20]), which is why strict EU regulatory limits and monitoring requirements apply to feed materials ([21]) ([22]). The maximum allowed levels for dioxins and PCBs in selected animal feed products are set by Directive 2002/32/EC. When comparing the maximum allowed contaminant levels

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([17]) FAO (2024). The State of World Fisheries and Aquaculture 2024 – Blue Transformation in action. Rome, https://doi.org/10.4060/cd0683en

([18]) ASC (2023). ASC Salmon Standard Version 1.4. Available here.

([19]) Santigosa et al. (2021). Microalgae Oil as an Effective Alternative Source of EPA and DHA for Gilthead Seabream (Sparus aurata) Aquaculture. Animals. https://doi.org/10.3390/ani11040971

([20]) EFSA (2025). Dioxins and PCBs.

([21]) Undesirable substances in the animal feed – information from DG SANTE https://food.ec.europa.eu/food-safety/animal-feed/undesirable-substances_en

([22]) Directive 2002/32/EC of the European Parliament and of the Council of 7 May 2002 on undesirable substances in animal feed https://eur-lex.europa.eu/eli/dir/2002/32/oj/eng for fish oil with those for other feed materials, it is notable that the limits for fish oil are significantly higher than those for plant-based materials. For example, the permitted level of dioxins in fish oil is more than six times higher than in plant materials used for feed, and, for non-dioxin-like PCBs, the difference is more than 17 times higher. Further discussion on this can be found in the original report ([23]) under section 3.3.

As avoiding contaminants in ocean water is challenging, materials derived from alternative sources and produced in controlled environments generally contain lower levels of the harmful substances. Microalgae used in aquafeeds are typically cultivated in closed facilities, which helps limit the introduction of contaminants. Evidence from interviews and reported literature indicates that replacing fish oil with algae oil, or a combination of algae and plant oils, leads to a significant reduction in PCBs and dioxins ([24]).

1.2.4. Nutritional requirements of key European fish species and optimal feed composition

There is no one-size-fits-all formulation for fish feed. Each species has specific nutritional requirements, and even within the same species, different life stages have distinct nutrient needs, which directly influence feed composition ([25]). Nevertheless, in general, the following nutritional elements are required for the main produced species of carnivorous fish ([26]),([27]),([28]),([29]),([30]):

– **Protein**: 40–50%

([23]) same as (1)

([24]) Belanger-Lamonde et al. (2018). Algal and Vegetable Oils as Sustainable Fish Oil Substitutes in Rainbow Trout Diets: An Approach to Reduce Contaminant Exposure. Journal of Food Quality. https://doi.org/10.1155/2018/7949782

([25]) For detailed information on nutrient requirements for Atlantic salmon, European seabass, gilthead seabream, and rainbow trout, please consult Tables 12-15 of the original report.

([26]) National Research Council. (2011). Nutrient Requirements of Fish and Shrimp. Washington, DC: The National Academies Press. https://doi.org/10.17226/13039

([27]) Zhang et al. (2023). Omega-3 long-chain polyunsaturated fatty acids in Atlantic salmon: Functions, requirements, sources, de novo biosynthesis and selective breeding strategies. https://doi.org/10.1111/raq.12882

([28]) FAO (n.d.). FAQs. Aquaculture Feed and Fertilizer Resources Information System. Available here.

([29]) Qian et al. (2020). Re-evaluating the dietary requirement of EPA and DHA for Atlantic salmon in freshwater. Aquaculture, 518. https://doi.org/10.1016/j.aquaculture.2019.734870

([30]) FAO (n.d.). Summary of dietary nutrient requirement and utilization of rainbow trout, Oncorhychus mykiss. Available here

– **Lipids**: 16–30%

– **EPA+DHA**: 1–2.5%

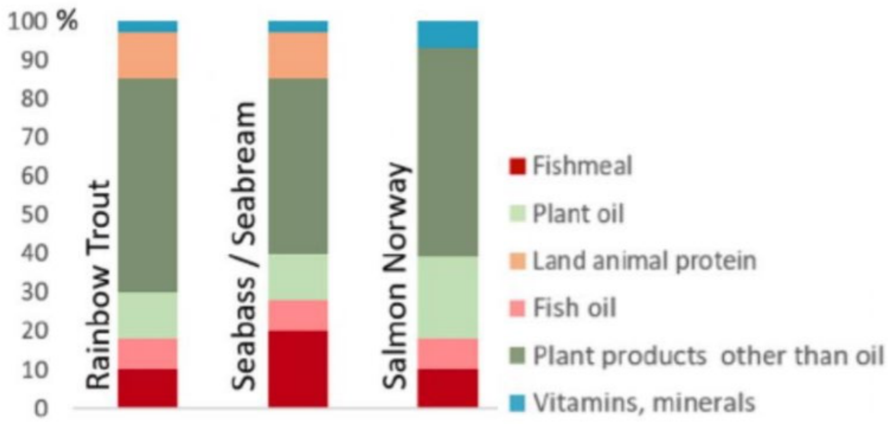
– **Carbohydrates**: 12–20% (max)

– **Micronutrients**: essential vitamins and minerals (trace), phosphorus (< 1.5%) and water (< 10%)

– Digestible energy: 15.5-20 kJ/g

– This composition is achieved with the inclusion of around 12% fish meal and 10% fish oil for Norwegian salmon ([31]) and rainbow trout ([32]), of which around 70% fish meal and 80% fish oil are from forage fish. Detailed information was not found for seabass and seabream, with studies mentioning total inclusion values of 20% fishmeal and 10-11% fish oil ([33]), ([34]), as can be seen in Figure 3.

Figure 3: Feed materials [%] commonly used in feeds for the grower phases of selected species (grower) in 2016



Source: Kreiss, C.M., Papathanasopoulou, E., Harmon, K.G. et al. (2020). Future Socio-Political Scenarios for Aquatic Resources in Europe: An Operationalized Framework for Aquaculture Projections. Front. Mar. Sci., 7, https://doi.org/10.3389/fmars.2020.568159

([31]) Aas et al. (2022). Utilization of feed resources in the production of Atlantic salmon (*Salmo salar*) in Norway: An update for 2020. Aquaculture reports. https://doi.org/10.1016/j.aqrep.2022.101316

([32]) Aas et al. (2022). Utilization of feed resources in the production of rainbow trout (*Oncorhynchus mykiss*) in Norway in 2020. Aquaculture reports. https://doi.org/10.1016/j.aqrep.2022.101317

([33]) Montero et al. (2023). Nutritional innovations in superior European sea bass (Dicentrarchus labrax) genotypes: Implications on fish performance and feed utilization. Aquaculture. https://doi.org/10.1016/j.aquaculture.2023.739486

([34]) Tampou et al. (2024). Growth performance of gilthead sea bream (Sparus aurata) fed a mixture of single cell ingredients for organic diets. Aquaculture reports. https://doi.org/10.1016/j.aqrep.2024.102105

1.2.5. *The use of plant-based feed materials as aquaculture feed*

The shift towards plant-based materials reflects efforts to reduce the dependency on fish-based materials in aquafeeds. Currently, fish-based materials make up only approximately 20% of salmon feeds, marking a significant decrease from approximately 75% in 1990 ([35]). For example, soybean, canola, corn, lupin, wheat, and barley are now widely used to replace fishmeal in feeds, while plant oils have largely replaced fish oil. However, these substitutions have led to the overall reduction of EPA and DHA in fish products, resulting in a lower nutritional quality of farmed fish ([36]).

Therefore, an ideal strategy is to incorporate marine micro-organisms, including microalgae – the primary producers of omega-3 fatty acids – into feed formulations. These micro-organisms not only provide a source of EPA and DHA but also contain high-quality protein and other bioactive compounds, making them a promising replacement for fishmeal and fish oil in aquafeeds.

2. Algae as an Alternative for Aquaculture Feed

2.1. Nutritional value of microalgae as a feed component

The use of algae in aquafeeds is not a novel concept and has been practised for many years. Microalgae have been commonly used as feeds in hatcheries and nurseries, as well as for broodstock ([37]) during periods when high lipid content is essential for meeting their biological needs ([38]). This type of algae offers several nutritional advantages for aquatic species through their richness in protein, essential fatty acids, vitamins and minerals ([39]). Microalgae are also used as a live feed for zooplankton, which in turn are fed to juvenile fish. Traditionally, live algae have been used at these life stages, but more recently, the use of algae concentrates and pastes in place of live algae has become increasingly popular ([40]).

([35]) IFFO (2021). Is feed evolution driving us towards new ingredients or into circularity? Available here.

([36]) Sprague et al. (2016). Impact of sustainable feeds on omega-3 long-chain fatty acid levels in farmed Atlantic salmon, 2006–2015. Scientific reports 6. https://doi.org/10.1038/srep21892

([37]) Shields, R., & Lupatsch, I. (2013). "5 Algae for aquaculture and animal feeds". Microalgal Biotechnology: Integration and Economy, edited by Clemens Posten and Christian Walter, Berlin, Boston: De Gruyter, pp. 79-100. https://doi.org/10.1515/9783110298321.79

([38]) Bruce et al. (1999). Development of broodstock diets for the European Sea Bass (Dicentrarchus labrax) with special emphasis on the importance of n−3 and n−6 highly unsaturated fatty acid to reproductive performance. Aquaculture, 144(1-4). https://doi.org/10.1016/S0044-8486(99)00071-X

([39]) Study on Feed for Aquaculture -”Aquafeed” 2025 (February 2026, still in drafting), 91.

([40]) Yarnold et al. (2019). Microalgal Aquafeeds As Part of a Circular Bioeconomy. Trends in Plant Science, 24(10). https://doi.org/10.1016/j.tplants.2019.06.005.

Obtaining precise figures on the current availability and usage of algae in aquafeeds is challenging, as the industry rarely discloses this information publicly. Consultations with industry stakeholders suggest that the average inclusion rate of algae in total feed is currently around 1%, consisting primarily of algae oil (2025).

The nutritional composition of certain microalgae species can be comparable to that of commonly used feed materials. Depending on the species and cultivation conditions, microalgae can contain up to 60% protein, 70% oil, or 60% carbohydrates. However, the nutritional profile of algae can vary significantly between species. Environmental factors such as light intensity, temperature, and nutrient availability also play a crucial role in determining the biochemical composition of algae.

Regarding polyunsaturated fatty acids (PUFAs), which are not provided by plant-based alternatives, their content can be above 50% of the total fatty acids in certain microalgae species. *Schizochytrium* sp. is an example of algae with an exceptionally high content of PUFAs, followed by *Nannochloropsis* sp., as can be seen in Table 1.

Table 1 – EPA and DHA content of oil derived from algae and selected fish species usually used as a source of fish oil [% fatty acids]

Oil source	EPA content	DHA content	Reference
Menhaden	12.2	7.9	([41])
Anchovy	18.3	8.5	
Sardine	16.9	21.9	
Nannochloropsis oceanica	24	/	([42])
Schizochytrium sp.	3.4	51.3	([43])

Besides PUFAs, essential amino acids can also be provided by algae. The content of selected microalgae species is shown in Table 2. The amino acid composition of fishmeal is also provided for comparison. Of the selected algae, biomasses from

([41]) https://www.feedtables.com/

([42]) Patil et al. (2007). Fatty acid composition of 12 microalgae for possible use in aquaculture feed. Aquaculture International. https://doi.org/10.1007/s10499-006-9060-3

([43]) Zeng et al. (2010). Development of a Temperature Shift Strategy for Efficient Docosahexaenoic Acid Production by a Marine Fungoid Protist, Schizochytrium sp. HX-308. Applied Biochemistry and Biotechnology. 164(3). http://dx.doi.org/10.1007/s12010-010-9131-9

Chlorella vulgaris, *Nannochloropsis* sp., *Schizochytrium* sp. exhibit an amino acid profile comparable to that of fishmeal.

Besides proteins and oils, microalgae are also a source of micronutrients and pigments. Pigments in algae are especially relevant for the aquaculture industry as the aquafeed industry primarily relies on synthetic pigments to improve flesh and skin coloration. Algae-derived pigments, such as carotenoids (e.g., astaxanthin from *Haematococcus pluvialis*), offer a natural alternative ([44]).

Moreover, when evaluating the nutritional properties of feed materials, it is crucial to consider their digestibility, as it serves as a key indicator of their nutritional value. Protein digestibility in fishmeal typically ranges between 70% and 92%. In comparison, the apparent digestibility coefficients (ADCs) for *Schizochytrium* sp. whole cells were around 85% for Atlantic salmon ([45]) and Rainbow trout ([46]). Digestibility of *Chlorella vulgaris*, *Nannochloropsis oceanica*, and *Nannochloropsis oculata* can also exceed 80% in rainbow trout and European seabass, even though their inclusion at 30% in the fish diets slightly decreased the total feed digestibility ([47]). These digestibility values may vary depending on the processing methods, algal species, and fish species. Overall, the digestibility of microalgae is comparable to that of fish- and plant-based materials, while cell disruption methods can significantly improve digestibility – particularly in algae species with thick cell walls such as *Chlorella* sp. and *Nannochloropsis* sp.

Even though macro algae can have negative effects on growth and feed conversion, when used at low levels as a functional feed material (< 10 %), it can also have positive effects. Macro algae promote health benefits, enhance the flavour of the farmed fish, act as a feeding stimulant, which indirectly also boosts protein intake ([48]). To produce a balanced algae-based feed as replacement for both fishmeal and fish oil, *Schizochytrium* sp. and *Nannochloropsis* sp. can serve as complementary sources: the first as a source of DHA and the latter as a source of EPA and proteins. Nevertheless, there may be other combinations or algae species not included in this research, or even species that are yet to be explored

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([44]) Ahmad, A., Hassan, S.W., Banat, F. (2022). An overview of microalgae biomass as a sustainable aquaculture feed ingredient: food security and circular economy, Bioengineered, 13(4). https://doi.org/10.1080/21655979.2022.2061148

([45]) Hart et al. (2021). Digestibility of Schizochytrium sp. whole cell biomass by Atlantic salmon (Salmo salar). Aquaculture. https://doi.org/10.1016/j.aquaculture.2020.736156

([46]) Belanger et al. (2021). Apparent Digestibility of Macronutrients and Fatty Acids from Microalgae (Schizochytrium sp.) Fed to Rainbow Trout (Oncorhynchus mykiss): A Potential Candidate for Fish Oil Substitution. Animals. https://doi.org/10.3390/ani11020456

([47]) Annamalai, S. N., Das, P., Thaher, M. I. A., et al. (2021). Nutrients and Energy Digestibility of Microalgal Biomass for Fish Feed Applications. Sustainability, 13(23), 13211. https://doi.org/10.3390/su132313211

([48]) Study on Feed for Aquaculture - "Aquafeed" 2025 (February 2026, still in drafting), 93.

([49]). For example, should a high EPA-yielding *Chlorella* strain become available, a combination of *Chlorella* sp. and *Schizochytrium* sp. for algae meal and oil production could also hold considerable promise. It is also important to consider that nutritional properties can vary greatly within species, depending on the specific strain and its growing conditions.

Finally, it is important to consider that the inclusion of algae as a source of protein must be done with caution due to their high mineral content. It is usually recommended to process the algae biomass into a protein-rich algae meal for its inclusion at high percentages in fish feed.

([49]) Table 3 of the 2025 CFI report on Algal Oil highlights other species beyond the ones encompassed in this report.

Table 2 – Amino acids in selected algae that are deemed essential for fish [% proteins]

Source	Arginine	Histidine	Isoleucine	Leucine	Lysine	Methionine	Phenylalanine	Threonine	Tryptophan	Valine	Reference
Fishmeal	5.8-6.4	2.0-2.4	3.7-4.5	6.5-7.5	6.9-7.7	2.6-2.9	3.3-3.9	3.9-4.3	0.9-1.2	4.5-5.4	([50])
Chlorella vulgaris	6.4-6.8	1.2-2.0	0.1-3.8	6.9-8.8	6.3-8.4	0.6-2.2	5.0-5.4	4.8-5.6	2.0-2.1	2.9-5.5	([51]), ([52])
N. oceanica	5.8	1.7	4.2	7.1	5.9	2.2	5.0	5.0	-	5.6	([53])
Schizochytrium sp.*	7.8	1.6	3.5	10.0	5.8	1.4	5.3	3.9	-	5.2	([54])

*no complete amino acid profile was found, only the amino acid profile of a protein hydrolysate produced from this microalga

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([50]) FAO (n.d.). Fish meal.

([51]) Safi et a. (2012). Influence of microalgae cell wall characteristics on protein extractability and determination of nitrogen-to-protein conversion factors. Journal of Applied Phycology. https://doi.org/10.1007/s10811-012-9886-1

([52]) Becker (2007). Micro-algae as a source of protein. Biotechnology Advances. https://doi.org/10.1016/j.biotechadv.2006.11.002

([53]) Guo et al. (2024). Comprehensive insights into microalgae proteins: Nutritional profiles and innovative applications as sustainable alternative proteins

in health and food sciences, Food Hydrocolloids. https://doi.org/10.1016/j.foodhyd.2024.110112

([54]) Cai et al. (2017). In Vitro Antioxidant Activities of Enzymatic Hydrolysate from Schizochytrium sp. and Its Hepatoprotective Effects on Acute Alcohol-Induced

Liver Injury In Vivo. Marine Drugs. https://doi.org/10.3390/md15040115

2.2. Multi-Criteria Analysis for the inclusion of algae in fish feed

A Multi-Criteria Analysis (MCA) was conducted to assess the suitability of various fish feed formulations and materials for aquaculture in Europe, listed below. A full description of the methodology and results can be found in the original report, including a comparison to insect-based feed.

1. “Standard” feed without alternative materials: it corresponds to the baseline option reflecting the most common feed formulation currently used in European aquaculture.

2. Algae-containing feed with fish oil and fishmeal: feed containing at least 3% microalgae. Algae oil or algae meal under this type of feed replaced only a portion of the fish oil or fishmeal included in the conventional feeds.

3. Algae-containing feed without fish oil or without fishmeal: feed containing at least 3% microalgae, but which differs from the previous category by entirely replacing either fish oil or fishmeal with other materials.

The main conclusions are:

- Algae-containing feed has a similar feed-to-fish conversion as standard fish feed. While slightly lower performance has been reported in formulations fully excluding fishmeal and fish oil, microalgae provide high levels of EPA and DHA and a rich amino-acid profile, which can support fish growth and nutritional quality.

- Both fish health and fillet quality are improved using algae materials, including a reduction in the presence of contaminants.

- Algae materials are costly, however, if some of the fish-based materials are replaced by plant-based ones, these tend to be cheaper and can offset the costs of the algae materials.

- Algae and plant-based materials have higher price stability than fish-based materials.

- The environmental impact of algae production is greatly influenced by the scale of production and can still be improved; nevertheless, algae inclusion reduces overfishing.

- Based on the findings of this analysis, algae-containing feeds show great potential as a sustainable alternative to standard feeds, particularly in increasing fish quality, enhancing price stability, and reducing dependency on forage fish. However, several challenges should be addressed to optimise their environmental and economic performance. More specifically, the environmental impact of algae-containing feeds is heavily influenced by the scale of production. Nevertheless, integrating algae production into circular economy frameworks can significantly improve environmental performance ([55]). A further analysis of the environmental impact of algal oil can be found in the "Sustainability" chapter of the 2025 CFI report on Algal Oil.

- An additional important factor that can enhance the use of algae-containing feeds in aquaculture is fostering consumer awareness and market demand. Educating consumers about the benefits of algae-containing feeds could drive demand for fish produced with these feeds and further enhance the growth of the aquaculture industry. Certifications or eco-labels showing the type of feed used for growing fish can help differentiate such products in the market ([56]).

2.3. Recommended levels of inclusion of algae in fish feed

Establishing minimum levels for the inclusion of non-fish-derived EPA and DHA sources in aquafeeds represents a crucial first step towards reducing dependency on wild fish for these essential nutrients. Over time, the contribution of EPA and DHA from alternative sources in aquafeeds should increase, potentially replacing, if not the entire amount, at least a significant share of what is currently supplied through wild-caught fish. The current limitations associated with the algae sector are lower production capacity and higher prices compared to traditional materials, thereby prohibiting a large-scale demand in the short term. Therefore, a minimum blend-in target of 25% EPA and DHA from non-fish-derived sources is recommended.

During the validation process, stakeholders confirmed that, in certain cases, such inclusion levels are already being implemented. In fact, some leading companies in the salmon farming industry are already applying a minimum of 30% EPA and DHA from alternative sources. While the recommended minimum target of 25% may seem modest for companies that already incorporate algae into aquafeeds, it may not appear like this for those who are yet to adopt alternative sources. A balanced consideration of all parties is needed. Although a full replacement of fish-derived EPA and DHA may be technically possible with algal sources, it may not be necessary, as by-products from seafood and aquaculture processing remain a valuable supplementary source for these important fatty acids.

It is important to note that a direct comparison between algae oil and fish oil is not straightforward. An inclusion of 1% algae oil does not equate to 1% fish oil, primarily due to the higher concentration of EPA and DHA in algae oil. Based on the interviews conducted, it was estimated that only two-thirds of the amount of algae oil is required to achieve EPA and DHA levels in feeds equivalent to those obtained from fish oil. Upon targeting 25% of the required EPA and DHA from non-

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([55]) Greene et al. (2022). Transforming the future of marine aquaculture: a circular economy approach. Oceanography, 35(4). https://doi.org/10.5670/oceanog.2022.213

([56]) Table 11 of the 2025 CFI study on Algal Oils brings existing certificates that support algal oil.

fish-derived sources such as algae oil, a feed that typically contains 12% fish oil could be reformulated to contain 9% fish oil supplemented with approximately 2% algae oil. However, more concentrated algae oil options are also available, allowing inclusion levels of 1.5% or lower to meet the requirements of farmed fish.

Regarding fish meal, feed industry experts believe that phototrophic algae species hold significant potential for use in aquafeeds. They expect that, within the next 5 years, an inclusion level of approximately 3% algae meal will be possible in aquafeed. However, it is unlikely that algae meal will soon become the primary substitute to fishmeal, as current processing technologies have not yet matured to support high inclusion levels. While some fishmeal protein may be replaced, algae biomass is more likely to be incorporated as a functional material – for example, to provide potential benefits from other components like pigments or beta-glucan, aiming to improve fish health and quality. Further technological advancements and additional research are essential for algae-based materials to become competitive with fishmeal or other alternatives in terms of both cost and performance.

2.4. Availability and reliability of algae to meet the demand of the aquaculture industry

The EU's consumption of fishmeal was 450,000 tonnes in 2022, while the amount of fish oil consumed in the EU can be calculated to be approximately 203,000 tonnes (57).

It is important to consider that most, but not all, fishmeal and fish oil is used in aquaculture. The EUMOFA report states that in 2021, 87% of the worldwide produced fishmeal and 75% of the fish oil were used in aquaculture. Projecting those figures to the consumption amounts for the EU, the amount used for aquaculture feed in the EU would equal about **390,000 tonnes of fishmeal** and around **152,000 tonnes of fish oil**.

Taking the example above, a reduction of 25% of fish oil use would result in a substitution of 38,000 tonnes of fish oil by 25,000 tonnes of algae oil on average. Considering that Schizochytrium sp. has, on average, 40% lipid content, this would require the production of around **63,000 tonnes of algae.**

The calculated numbers were discussed with producers of algae and algae oil. They found these figures realistic; however, it is important to note that, while the method and sources used for the calculations were as requested, they recommended calculating the values for fish oil and algae oil based on the amounts of EPA and DHA. This approach may provide more accurate results, particularly given the variability in the concentrations of these targeted compounds, especially in algae oil.

([57]) EUMOFA (2023). Fishmeal and Fish Oil. Available here.

The global market for EPA and DHA omega-3 reached a value of USD 2.38 billion in 2024, with a total volume of 131,183 metric tonnes. Current estimates put the algae-derived EPA and DHA production at around 20,000 metric tonnes in 2025 ([58]).

For algae meal, calculating with the estimate of a 3% inclusion rate within the next 5 years (until 2030), the requirement for EU aquaculture feed could be **12,500 tonnes**, resulting in a replacement of an equal amount of fish meal by 2030.

In 2022, it was estimated that approximately **130,000** tonnes of microalgae (dry weight) were produced globally, with a market value of 2.6 billion euros. This figure likely includes all types of microalgae, also including cyanobacteria and Labyrinthulomycetes, such as *Schizochytrium* sp. ([59]). In Europe, microalgae production accounted for only around 2% of this value. Therefore, it seems the global microalgae production currently cannot meet the foreseen demand for algae oil and meal in the EU. If local production is expected, an even larger increase in production capacity is required.

Approximately 73% of global *Nannochloropsis* production is already used in the aquafeed market. This species is primarily utilised in hatcheries due to its nutritional value, particularly its protein, EPA, and pigment content ([60]). The production of *Nannochloropsis* in the EU was estimated to be 21 tonnes in 2021, originating from 25 companies. However, this production volume may be an underestimate, as other sources have suggested significantly higher figures ([61]). Looking ahead, a compound annual growth rate (CAGR) of 9.4% is projected for the global *Nannochloropsis* market between 2024 and 2031, reaching 122 tonnes by 2031, with an estimated market value of 14 million USD. The growing demand for algal protein is expected to be the primary driver of this growth. Europe is estimated to hold a 35.7% share of the total value of the *Nannochloropsis* market ([62]).

Schizochytrium sp. is cultivated heterotrophically, meaning it does not require light but instead uses a carbon source such as sugar or glycerol for growth. Although current production volumes are not publicly available, commercial large-scale production of *Schizochytrium* sp. for algae oil extraction already exists. For

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([58]) https://www.feedinnovation.org/algal-oil-2025-state-of-the-industry-report

([59]) EUMOFA (2023). Fishmeal and Fish Oil. Available here.

([60]) Lawande & Bombe (2024). Nannochloropsis Market Size, Share, Forecast, & Trends Analysis by Form (Frozen, Liquid, Powder, Fresh Pastes), Application (Aquafeed, Extraction Companies)—Global Forecast to 2031. Available here.

([61]) Same as (51).

([62]) Same as (60)

example, Corbion ([63]) and Veramaris ([64]) are two well-known producers, supplying oil derived from *Schizochytrium* sp. for use in aquafeeds.

The great strength of microalgae as a source of protein or oil to replace fish-based materials lies in their reliability. Unlike forage fish sourced from the ocean, microalgae are typically cultivated in controlled environments, offering increased protection from external factors. This advantage has been frequently emphasised by various stakeholders during the consultations and applies to the microalgae species discussed in this report.

Most large-scale algae oil production occurs outside Europe due to limited fermentation facilities, high costs, and sub-optimal conditions, but solving these challenges could boost the European algae market for aquafeed.

However, most of the large producers of algae oil are currently not producing in Europe. According to some industry stakeholders interviewed, the challenge lies in the lack of large-scale algae fermentation facilities with access to a low-cost sugar source with a relatively low carbon footprint in Europe. According to the industry stakeholders, the conditions in Europe are not ideal for producing such large quantities of suitable sugar crops for algae production. The geographical position with sub-optimal climatic conditions outside of southern Europe and certain financial-economic aspects, such as higher labour or land costs, can be a hurdle. Finding solutions to these issues would provide a significant boost to the algae market, enabling it to better serve the needs of the European aquafeed industry. A great benefit that was pointed out and highly valued by the interviewed stakeholders was the fact that logistic costs and import costs could be significantly reduced if large scale production facilities would be established directly in Europe. Additionally, the proximity to major markets like Norway, which requires large volumes of EPA and DHA rich oil to produce Atlantic salmon, would be a considerable advantage. Another strength of Europe regarding the microalgae sector is its strong position as a science and technology base, as well as its research and development funding policies ([65]).

It is important to note that some companies already make use of these advantages, as they are already producing algae for aquafeed in Europe. One example is the algae oil producer MiAlgae ([66]). They have solved the issue of the availability of suitable low-cost sugar crops in a different way: they utilise distillery co-products from the whisky industry in Scotland, also benefiting from proximity to

([63]) More information can be found here: https://www.corbion.com/

([64]) More information can be found here: https://www.veramaris.com/

([65]) Vigani et al. (2014). Microalgae-based products for the food and feed sector: an outlook for Europe, Publications Office. https://data.europa.eu/doi/10.2791/333

([66]) More information can be found here: https://mialgae.com/products/mialgaefish/

the whisky distilleries. A list of potential side-streams rich in sugar and available in Europe is discussed in Chapter 7 of the original report, such as sugar beet molasses, wood wastes, glycerol, and by-products from breweries, distilleries, and the dairy and fruit industries.

2.5. Economic viability of including algae-based materials in fish feed

The economic viability of algae-containing feed is a critical factor influencing its adoption in the aquaculture sector. At present, the production of algae-containing feed is generally more costly than standard feed. As such, financial support is essential to enable the industry to scale up and improve competitiveness. An estimation of the production costs of algae oil can be found in the 2025 CFI report on Algal Oils.

Algal oil production costs vary by cultivation method. Heterotrophic fermentation is currently the most cost-efficient, with commercial-scale costs around USD 14,500 per tonne of oil (~USD 29,000 per tonne EPA+DHA), driven mainly by carbon feedstocks, energy, and capital-intensive processing. Phototrophic systems are significantly more expensive, with closed photobioreactors ranging from USD 30,000–80,000 per tonne of oil and open ponds limited by productivity and contamination. Heterotrophic systems remain two to five times cheaper, with future savings relying on lower-cost feedstocks, improved energy efficiency, and maximized facility utilisation.

Algal oil offers a sustainable alternative to fish oil, whose production includes both capture and processing costs, typically around USD 10,000–15,000 per tonne of crude oil. Making it comparable with heterotrophic algae fermentation (see above). Algae provide controlled, scalable production independent of wild fisheries, with potential future cost reductions from cheaper feedstocks, energy efficiency, and maximized facility use. Combined with growing demand for plant-based and sustainable omega-3s, algae oil has strong market potential for human nutrition and aquafeed.

Financial incentives are key to scaling up sustainable algae cultivation and supporting the transition from fish-based to algae-based feed in aquaculture. The EU provides extensive public funding through the Common Agricultural Policy, the Green Deal, the Recovery and Resilience Facility, and programs like InvestEU, targeting climate-friendly investments and reducing financial risks for producers, including SMEs. By mobilizing private finance and applying the EU Sustainable Finance framework, including the EU Taxonomy for Sustainable Activities, the EU can make algae-based feed production more economically attractive. Expanding these measures to explicitly include algae cultivation would accelerate its adoption, increase production scale, and help replace fishmeal and fish oil, promoting a more sustainable aquaculture sector. Individual regulations and initiatives relevant to aquaculture that arose from the Green Deal have introduced a range of financial instruments and incentives specifically designed to support sustainable practices and the adoption of innovative solutions. One of the most direct ways the EU supports sustainable aquaculture is through dedicated funding programmes. The European Maritime, Fisheries and Aquaculture Fund (EMFAF) ([67]) provides financial support for sustainable aquaculture as part of its broader objectives to promote the sustainable development of fisheries, aquaculture, and maritime economies.

Financial and regulatory incentives have shown strong potential in guiding aquaculture practices toward greater sustainability across Europe, with several initiatives already delivering measurable results. Among these, flexible licensing systems have proven particularly effective, blending environmental safeguards with market-responsive mechanisms to foster the uptake of sustainable technologies. One notable example is Norway’s eco-technology licensing scheme, which leverages performance-based criteria and innovation incentives to reduce environmental impacts while enabling continued industry growth.

Implementation results after three years reveal significant environmental benefits, with licensed farms showing 40-60% reductions in seabed pollution compared to conventional operations. The scheme has successfully stimulated market transformation, creating a premium segment for eco-certified salmon that commands 15-20% higher prices. It has also accelerated the adoption of recirculating aquaculture systems (RAS), demonstrating how innovation-linked incentives can rapidly drive the uptake of environmentally sustainable practices. That could be an approach that could similarly accelerate the adoption of algae-based feeds across the EU.

Direct financial support

Subsidies and direct funding are among the most widely discussed financial incentives in the literature. The primary effect mechanism of direct support is cost reduction, enabling producers to invest in algae-based feeds without incurring financial disadvantages. Subsidies have been successfully used in agriculture to promote environmentally friendly practices, demonstrating their potential for aquaculture. One of the key merits of subsidies is their ability to provide immediate financial relief, ensuring that sustainability goals do not come at the expense of economic viability. Furthermore, subsidies can be designed with conditional requirements, ensuring that recipients meet sustainability benchmarks, for example by using certified algae-based feed or adopting innovative feeding technologies.

However, a major drawback is the fiscal burden on public budgets, and poorly designed subsidies can lead to market distortions, creating dependencies that may not be sustainable in the long term.

([67]) More information can be found here: https://oceans-and-fisheries.ec.europa.eu/funding-and-investment/emfaf_en

Market-based instruments

Certification schemes and eco-labels, such as the Aquaculture Stewardship Council ([68]) (ASC) and the Marine Stewardship Council ([69]) (MSC), are frequently discussed in the literature as market-based incentives for sustainable aquaculture. These certifications allow producers to access premium markets and charge higher prices for their products, creating a financial incentive to adopt sustainable practices.

Larger producers are willing to invest in certification and eco-labels to gain a competitive advantage relative to other fish farmers and to avoid future non-compliance with stricter market requirements ([70]). However, for small-scale producers, certification may not be a viable option, even in the presence of strong market demand, as complexities and costs associated with certification limit the ability of small-scale producers to benefit from premium pricing. Processors and retailers of farmed fish also play a critical role in driving certification and eco-label adoption, since they often demand certification from their suppliers, motivated by the potential to obtain a competitive advantage and gain or maintain access to certain markets.

Tax incentives are another important tool for promoting sustainable aquaculture ([71]). Tax incentives, such as reduced VAT rates (e.g., through the revised VAT Directive EU 2022/542 ([72])) or tax credits for feed manufacturers using algae-based materials, can lower production costs and encourage investment in sustainable alternatives. Additionally, environmental taxes or pollution levies can discourage unsustainable practices. By internalising the environmental costs of aquaculture, these fiscal policies create economic incentives for producers to adopt cleaner and more efficient practices. For example, since 2013, Denmark has applied a pesticide load tax according to which the most harmful pesticides carry higher taxes, incentivising farmers to switch to less toxic alternatives.

The main advantage of tax incentives is their ability to encourage private-sector investment without direct government spending. They provide long-term support without requiring constant financial outflows, making them fiscally sustainable.

([68]) More information can be found here: https://asc-aqua.org/

([69]) More information can be found here: https://www.msc.org/

([70]) Chikudza et al. (2020). "Producer Perceptions of the Incentives and Challenges of Adopting Ecolabels in the European Finfish Aquaculture Industry: A Q-Methodology Approach," Marine Policy 121, 104176. https://doi.org/10.1016/j.marpol.2020.104176

([71]) Hishamunda et al. (2014). "Policy and Governance in Aquaculture Lessons Learned and Way Forward" (FAO). Available here.

([72]) https://eur-lex.europa.eu/eli/dir/2022/542/oj/eng

However, tax incentives may be less effective in markets where upfront investment costs are prohibitively high, and their impact depends on how businesses and producers respond to the financial incentives.

The concept of **Payment for Ecosystem Services** (PES) has gained traction in the literature as a financial incentive for sustainable aquaculture. PES schemes compensate producers for the environmental benefits they generate, such as carbon sequestration, water purification, or biodiversity conservation. PES schemes can be funded by governments, non-governmental organisations (NGOs), or private entities, and provide a direct financial incentive for producers to adopt practices that enhance ecosystem health. PES can improve ecological outcomes while generating additional revenue streams for fish farmers. However, establishing measurable criteria and ensuring effective monitoring can be challenging.

Risk-sharing instruments

Green/Blue bonds and other sustainable finance instruments are increasingly being explored as tools to fund sustainable aquaculture projects. Green/Blue bonds allow investors to support environmentally friendly initiatives, such as the development of sustainable aquaculture systems or the production of algae-containing feeds. The proceeds from these bonds can be used to finance projects that reduce environmental impacts and promote resource efficiency ([73]) and support the transition from fishmeal- and fish oil-based feed to algae-based alternatives. For example, on 2 April 2025, the European Investment Bank (EIB) issued €3 billion in green bonds aligned with the new European Green Bond Standard, with proceeds earmarked for projects that contribute substantially to EU climate and environmental objectives, such as clean energy, sustainable transport, and water infrastructure and innovative, sustainable aquaculture feed solutions.

Beyond bonds, impact investing and blended finance models present significant opportunities to attract private capital into sustainable aquaculture. While these instruments have historically received limited attention in the context of sustainable fishing and aquaculture, their potential to reduce investment risks and support innovative algae-based feed projects. Impact investing seeks to generate positive social and environmental benefits alongside financial returns, making it well-suited to funding sustainable aquaculture initiatives. According to the FAO, there is a significant opportunity to leverage $500 billions of impact investment capital to support the blue economy, including sustainable aquaculture. Blended finance, which combines public and private investment, can further mitigate risks and enhance the attractiveness of sustainable aquaculture projects to private investors. Such instruments, including bonds, impact investing, and blended finance, can support long-term funding and sector

([73]) FAO (2020). "FAO's Blue Growth Initiative: Blue Finance Guidance Notes Impact Investment," Available here.

growth, but require strong governance frameworks to ensure funds are allocated effectively.

2.6. Regulatory landscape for including algae-based materials in fish feed

The original report brings a full list of regulations applicable to the production of algae-based feed materials in Chapter 5, such as the Animal Feed Regulation ([74]) and the Catalogue of Feed Materials ([75]), amongst others.

To assess the most pressing regulatory issues of algae as feed materials, surveys and interviews were conducted with relevant industry stakeholders. It was found that there were no immediate issues with the regulations themselves, indicating that the regulatory landscape is functioning well with respect to the production of algae-containing feed and algae feed materials.

However, a few challenges in the application of these regulations were mentioned during the interviews. These include the complexity of the regulatory landscape and the difficulties associated with using new algae species. The most frequently raised concern was that the regulatory landscape is very challenging to navigate. This complexity can be particularly burdensome for smaller feed operators, who may lack the resources and expertise to effectively interpret and comply with the intricate and fragmented European feed law, which is dispersed across various regulations and directives. This situation can lead to confusion and potential non-compliance, hindering their ability to operate effectively in the market. Providing clear guidelines or a public consultation option for algal feed operators could be of great benefit for the industry.

Another aspect that was highlighted relates to the use of new algae species in feed. The safety assessments for new species are both costly and time-consuming, creating a barrier to innovation in the feed industry. By including new algae species in the Novel Food catalogue, options for their use in feed can expand. These species would have already undergone safety assessments, and their suitability for human consumption would have been assessed. While this does not guarantee their suitability for feed applications, it still indicates their potential suitability and compliance for feed, which would be a great advantage for the feed industry. Simplifying and accelerating the novel food authorisation process would therefore also facilitate faster development within the feed industry and enable the exploration of potentially more effective algae species.

2.7. Market examples

Several companies produce algae materials for aquafeed, and feed manufacturers are incorporating these into their products. The adoption of these feeds in

([74]) https://eur-lex.europa.eu/eli/reg/2009/767/oj/eng

([75]) https://eur-lex.europa.eu/eli/reg/2017/1017/oj/eng aquaculture is on the rise. Regarding the production of algae oil for aquaculture feed, currently, two major suppliers exist: Veramaris and Corbion.

Veramaris (DSM & Evonik Joint Venture)

Veramaris is a leading biotechnology company specialising in the production of algae-derived omega-3 oils, primarily for use in aquaculture feed. A joint venture between DSM and Evonik, Veramaris produces its oil from natural marine microalgae through a fermentation-based process, eliminating the sole reliance on wild-caught fish as a source of EPA and DHA. Its large-scale production facility is located in Nebraska, and its headquarters are in the Netherlands.

Veramaris is the first – and currently only – ASC-MSC certified microalgae oil producer for fish and shrimp feeds and has won multiple awards for its algae oil as an alternative feed material. The algae oil contains 65% EPA + DHA. The product is used by major European feed producers, and the company has established several partnerships, including collaborations with Skretting, Santa Priscila, and Pacific Coral Seafood.

Corbion

Corbion algae oil is used by leading feed manufacturers and is a key material in salmon feeds across Norway and other European markets. Corbion produced algae-based omega-3 and other lipid solutions in a controlled environment via closed system fermentation, harnessing the power of microalgae (*Schizochytrium* sp). Their omega-3 products are used in over 2 million MT of fish feed annually. While Corbion's initial focus was primarily centred around supplying omega-3 in aquaculture, increasing demand coming from other markets is observed, such as pet food and human nutrition.

Other companies

Additionally, several other companies are producing algae oil or algae meal for aquaculture, such as MiAlgae (algae oil for aquaculture; located in the UK), Fermentalg ([76]) (algae protein concentrate for aquaculture; located in France) or Algaevita ([77]) (omega-3 rich algae meal for aquafeed; located in Slovenia).

In the original report, Chapter 6, three successful industry examples are presented. This includes direct insights from an algae feed producer, an aquafeed manufacturer utilising alga, and an aquaculture company that uses

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([76]) More information here: https://www.fermentalg.com/our-biosolutions/galdieria-blue

([77]) More information can be found here: https://algaevitanutrition.com/

algae-containing feed. Further examples of algae adoption in fish feed are given in Annex I.

3. Conclusions and recommendation

Based on the best available knowledge and analysis presented in this document and relevant reports and studies, this subheading provides conclusions and recommendations on promoting replacement of fish-based feed with algae-based aquafeed in the EU.

3.1. Conclusions

1. **Algae is a viable and technically feasible alternative to fishmeal and fish oil**

The reliance on wild-caught forage fish for aquafeed is environmentally and economically unsustainable, given ongoing overfishing, finite marine resources, and the projected supply gap driven by aquaculture growth. There is therefore a clear structural need for viable alternatives. The original report confirms that algae, particularly selected microalgae species such as *Schizochytrium sp.*, *Nannochloropsis sp.*, and *Chlorella sp.*, can technically replace fishmeal and fish oil. Microalgae provide essential omega-3 fatty acids (EPA and DHA), are rich in protein with suitable amino acid profiles, and address key nutritional limitations of purely plant-based feeds. While macroalgae are less suitable as bulk replacements, both micro- and macroalgae can deliver valuable functional and bioactive compounds that enhance fish health. Processing techniques can further improve digestibility and nutrient availability, depending on species-specific characteristics.

2. **Algae-containing feeds enhance performance, fish health, and food safety while reducing environmental impact**

Evidence from trials and multi-criteria Analysis demonstrates that algae-containing feeds achieve comparable feed conversion ratios (FCR), specific growth rates (SGR), and overall fish health relative to conventional fish-based formulations. In addition, replacing marine ingredients with algae can improve fish quality and significantly reduce contamination levels, particularly PCBs and dioxins, which predominantly originate from marine-derived feed components. Even partial substitution reduces the Forage Fish Dependency Ratio (FFDR), contributing to improved ecosystem outcomes. While total replacement of fish-based ingredients is technically feasible, a combined approach, including algae, sustainable by-products, and other alternative proteins, represents a more practical pathway for industry implementation.

3. **Algae-based feeds promote environmental sustainability and support marine ecosystem recovery**

The environmental performance of algae-based feed depends strongly on production systems and scale. Although some small-scale life cycle assessments indicate higher CO_2 emissions, large-scale and circular production models demonstrate significant improvements. For example, commercially available algae-based DHA products have shown 30 - 40% lower climate impacts compared to fish oil. Importantly, substituting forage fish with algae reduces pressure on wild fish stocks and marine biodiversity, supporting regenerative aquaculture practices. The integration of residual biomass streams and circular approaches can further enhance sustainability outcomes.

4. **Algae-based feeds offer economic resilience and market opportunities despite higher costs**

Currently, algae-based feed ingredients are on average around 10% more expensive than conventional fish-based ingredients, though algae oil has at times been cost-competitive. However, algae production in controlled environments offers greater price stability and resilience against external shocks such as climate events or fluctuations in wild fish stocks. Inclusion rates of 10-15% in salmon and trout feeds and 20-25% in seabass and seabream appear technically feasible, although cost remains a limiting factor, particularly for lower-value species. Setting measurable targets, such as achieving 25% of EPA and DHA from non-fish sources, could stimulate demand and support economies of scale.

5. **Policy, regulatory and financial frameworks are key to accelerating algae feed adoption**

Current regulatory framework already permits the use of algae in aquafeeds, but a comprehensive enabling environment is needed to accelerate adoption. A holistic framework combining regulation, financial instruments, market-based incentives, and sustainability standards is essential. Correcting market distortions, such as removing subsidies for unsustainable feed inputs and introducing tax incentives for sustainable alternatives, could significantly shift market behaviour. Inclusion of sustainable aquaculture and algae-based feed in the EU Taxonomy, alongside innovative financing mechanisms such as blue bonds, would further mobilise private capital. Establishing FFDR targets and strengthening contaminant regulations under the ALARA principle are feasible policy tools to drive uptake.

6. **Scaling algae feed production requires infrastructure investment and continues innovation**

By 2030, modest inclusion rates, such as 3% algae meal and 5% algae oil, could replace substantial volumes of fishmeal and fish oil in the EU, significantly reducing marine resource dependency. However, scaling up production will require major investments in infrastructure, particularly large-scale fermentation capacity and access to sustainable, low-cost sugar sources. While viable feedstocks exist in Europe (e.g., molasses, brewery by-products, wood waste), further research and optimisation are necessary. Continued R&D on strain selection, processing technologies, and nutrient bioavailability, as well as valorisation of residual biomass streams, will be critical for improving cost-efficiency and sustainability.

Overall, algae represent a strategically important component of a more resilient, circular, and sustainable EU aquafeed system. With targeted policy support and continued innovation, algae-based feed can play a decisive role in reducing dependence on wild fish resources while supporting the long-term growth of sustainable aquaculture.

3.2. Recommendations

1. **Promote gradual increase of algae in aquafeeds - for feed manufacturers and aquaculture producers**

It is recommended that a complete replacement of fish-based ingredients with algal alternatives be considered as a long-term target, as it is technically feasible. Feed formulations could aim for algae meal and oil to account for 10–15% of total feed for salmon and trout and approximately 20–25% for seabass and seabream, which would correspond to replacing the majority of current whole forage fish-derived ingredients. However, due to current cost constraints, especially for lower-value species, a phased approach is advised. A practical and scalable strategy would involve combining algae with other alternative ingredients and sustainably sourced fish-based components, including trimmings and offal from aquaculture operations, to optimize both nutritional and economic outcomes.

2. **Introduce minimum targets for non-fish-derived EPA+DHA - for feed manufacturers and aquaculture producers**

Feed manufacturers and aquaculture producers should aim for at least 25% of total EPA+DHA to be sourced from non-fish ingredients as an initial target. Stakeholders are also encouraged to periodically review and adjust this target as the market for alternative ingredients evolves, to support sustainable sourcing and reduce dependency on wild fish stocks.

3. **Reduce the forage fish dependency ratio (FFDR) - for feed manufacturers, aquaculture producers and policy makers**

Feed manufacturers, aquaculture producers, and relevant policy makers should aim to maintain an FFDR (including FFDRm and FFDRo) around current average values as a baseline. Stakeholders are encouraged to offer or seek incentives for feeds that achieve a significantly lower FFDR, promoting the use of by-products and alternative ingredients. These targets should be integrated with additional indicators, such as LCAs and certifications, to ensure a holistic approach to sustainability. As aquaculture production grows and forage fish remain a limited resource, FFDR targets should be regularly reviewed and potentially lowered every five years to reflect evolving conditions and maintain environmental benefits.

4. **Include the ALARA principle for feed contaminants - for regulators and policy makers**

Regulators and policy makers could consider explicitly applying the ALARA principle (“As Low As Reasonably Achievable”) to aquafeeds in the next evaluation of Directive 2002/32/EC (on undesirable substances in animal feed). Integrating ALARA may help further reduce contaminant levels and support safer, more sustainable feed practices across the aquaculture sector.

5. **Reduce allowable contaminant levels - for regulators and policy makers**

Regulators and policymakers should consider revising Directive 2002/32/EC to lower the current maximum limits for dioxins and for the sum of dioxins and dioxin-like PCBs. Lowering the limits for non-dioxin-like PCBs should also be assessed where feasible. In addition, reducing the existing action thresholds for dioxins and dioxin-like PCBs could further strengthen feed safety and enhance protection for aquaculture species and consumers.

6. **Consider developing complementary industry standards for algae feed - for industry associations, feed manufacturers and regulators**

Industry associations, feed manufacturers, and regulators should consider developing new standards to address key gaps in the algae feed sector, complementing existing industry (78) standards. These standards may cover the following areas:

- Claims: Define potentially suitable claims (e.g. nutritional, environmental, health) for algae and algae-containing feed, supporting their responsible use and market transparency;

- Origin of biomass: Specify appropriate methods to verify the origin of biomass, enhancing accurate labelling and traceability;

- **Substrates and cultivation inputs**: Define criteria and verification methods for substrates and nutrient inputs used in algae cultivation (including growing media), ensuring safety, traceability, and consistency with EU fertilising products and feed regulations, while minimising contamination risks and supporting sustainable production practices.

- Contaminants: Specify analytical detection and quantification methods for contaminants in algae, including a comprehensive overview of known algae contaminants;

- Water management: Establish guidelines for water reuse and consumption measurement in algae cultivation;

(78) To duly consider European and ISO standards already developed and under development and identify a priority list of standards to be developed

- Preservation methods: Define sustainable preservation and storage methods for algae according to intended end use.

7. Moving towards a supportive framework for algae-based feed – for EU policymakers and industry stakeholders

Within current financial constraints and the timeline of the ongoing EU Multiannual Financial Framework, a gradual and pragmatic approach could be considered to strengthen support for the inclusion of algae in aquafeed. Rather than creating entirely new instruments, efforts could build on existing policies and funding mechanisms.

In this context, policymakers and stakeholders could explore:

- Further developing an enabling regulatory and policy environment, including clearer guidance, voluntary certification schemes, and targeted technical support.
- Reviewing existing fiscal measures to better align incentives with sustainability objectives, where economically and politically feasible.
- Assessing the potential integration of sustainable aquaculture, including algae-based feed solutions, into the EU Taxonomy framework.
- Facilitating access to existing financial instruments (e.g. guarantees, blended finance, or blue economy initiatives), particularly for SMEs.
- Gradually improving data availability, monitoring, and transparency to support evidence-based policymaking.

Such stepwise measures could help create more favourable conditions for scaling up algae cultivation and reducing reliance on fish-based feed, while remaining aligned with current budgetary realities and legislative processes.

Annex A Examples of market adoption of algal oil in aquaculture

Danish aquafeed producer BioMar has found, after 10 years of research, that "algal oils can fully replace fish oil with no negative impact on growth, feed conversion, or product quality across different species and farming stages." They produce fish feed containing this ingredient and have sold over 4 million tonnes of such products.

- https://www.biomar.com/insights/insights-hub/the-evolution-of-nutrients-in-aquafeeds

Skretting is the global aquaculture feed division of Nutreco. Operating in 17 countries and based in Norway, it provides sustainable nutritional solutions for over 60 species, from hatch to harvest. Since 2016, it has been using algal oil in the formulation of its fish feed products.

- https://www.skretting.com/en/news-and-stories/skretting-to-offer-algal-oil-breakthrough/

The American giant Cargill also mentions using algal oil in the formulation of their aquafeed.

- https://www.cargill.com/sustainability/aquaculture/aquaculture-feed-ingredients

Norwegian salmon farm Lingalaks has been feeding its salmon since before 2019 with omega-3 marine algal oil from Veramaris, formulated into feed by the manufacturer Skretting.

- https://lingalaks.no/en/sustainable-aquaculture/
- https://www.fishfarmingexpert.com/france-linglaks-norway/french-retailer-begins-sales-of-algal-oil-fed-salmon/1269883

A leading global seafood company, Mowi ASA is the largest producer of Atlantic salmon. Its 2023 harvest of 475,000 tonnes represented roughly 20% of the worldwide market. Mowi perceives algal oil as an interesting emerging feed raw material for use in their salmon feed.

- https://mowi.com/es/wp-content/uploads/2024/05/240507-Mowi-Emerging-Feed-Raw-Materials-Policy-1.pdf

The sales of salmon increased by 12% in the Match supermarket chain in France after they started offering salmon fed with algal oil, which boosted its EPA and DHA content, indicating market demand and approval of the product. The supermarket chain Cora followed with the introduction of salmon fed with the Veramaris algal oil, and soon after the German group Kaufland also introduced a similar product in their supermarkets.

- https://www.seafoodsource.com/news/premium/foodservice-retail/french-retailer-cora-now-selling-salmon-raised-on-veramaris-algae-based-feed
- https://www.salmonbusiness.com/kaufland-becomes-first-german-retailer-to-introduce-algal-fed-salmon/

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